Modeling the ground resistivity from unfrozen water content in fine-grained high-latitude permafrost

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MODELING THE GROUND RESISTIVITY FROM UNFROZEN WATER CONTENT IN FINE-GRAINED HIGH-LATITUDE PERMAFROST

Session 7: Frozen ground physics

Running for the PYRN Award

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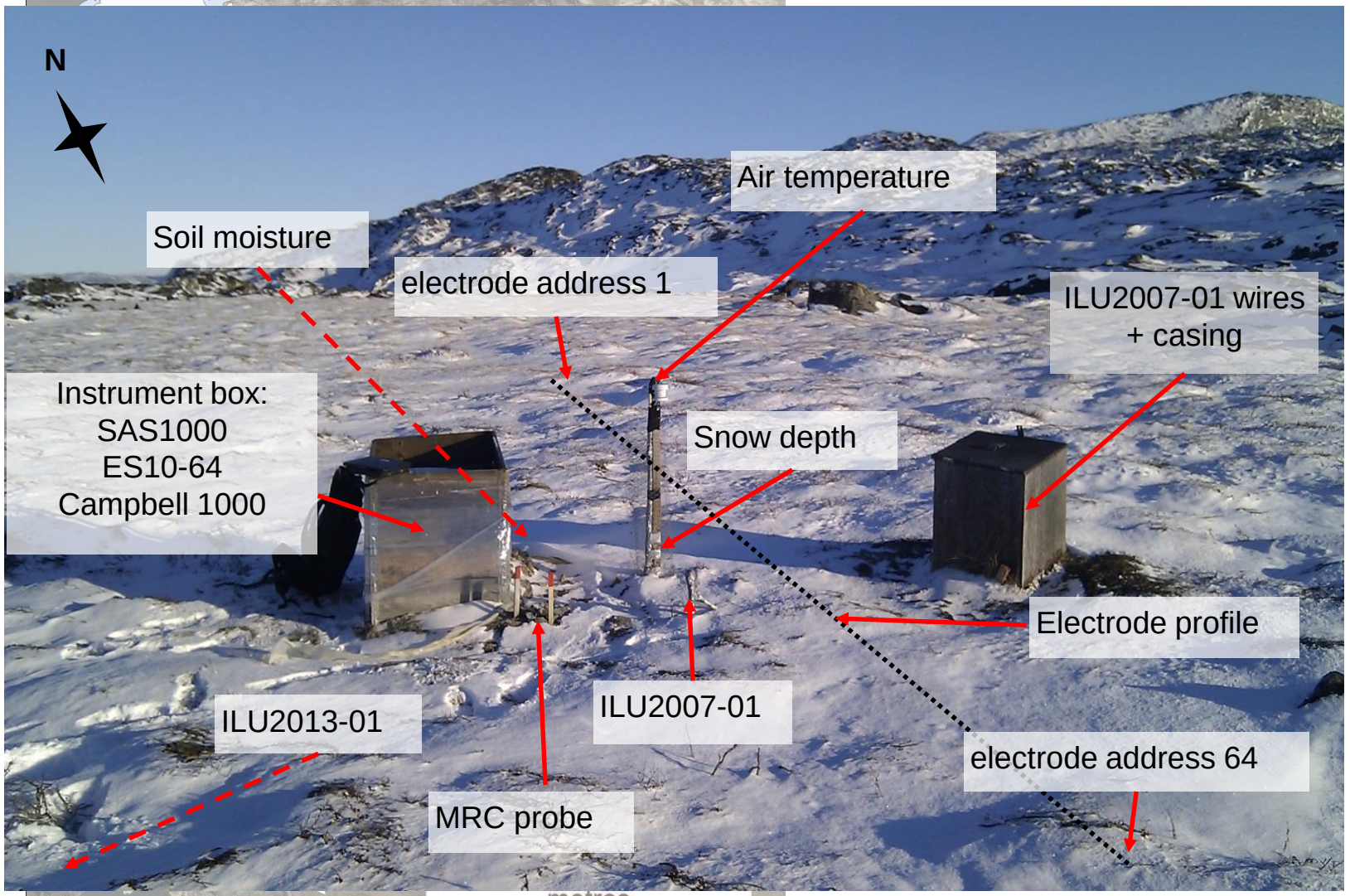
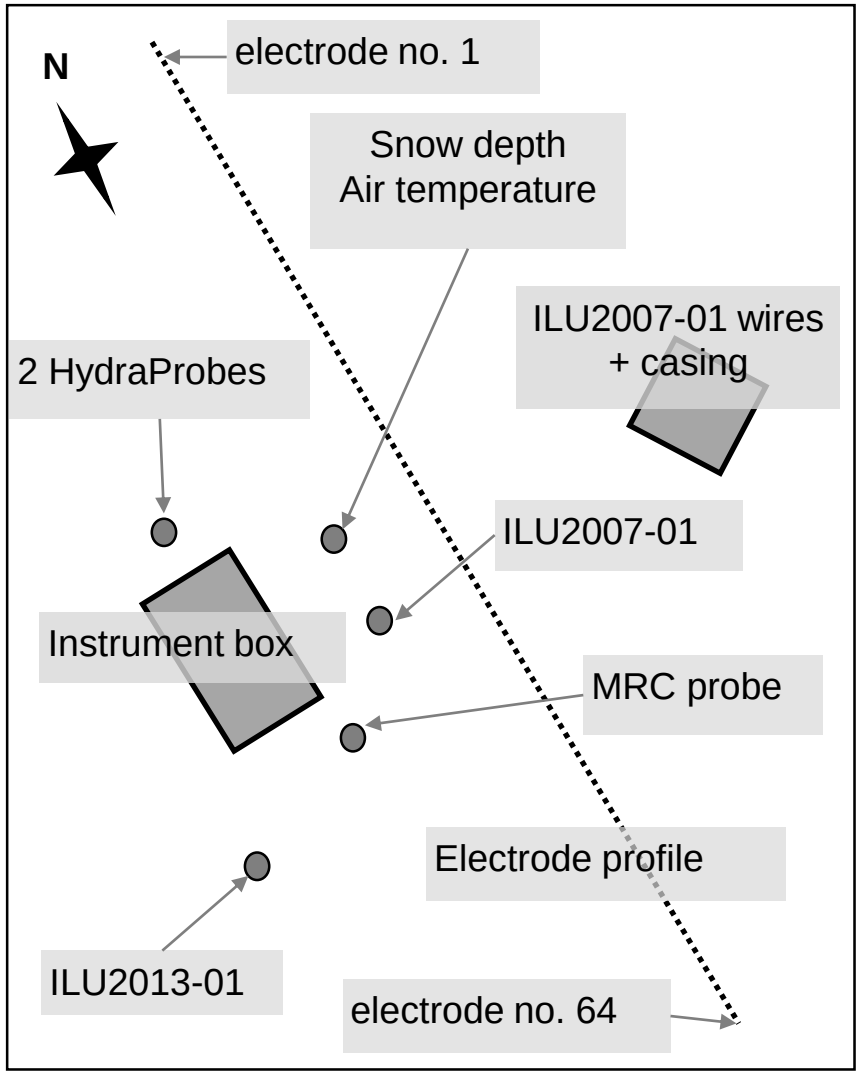
Monitoring station in Ilulissat, West Greenland (69° 14´ N, 51° 3´ W, 33 m a.s.l.)

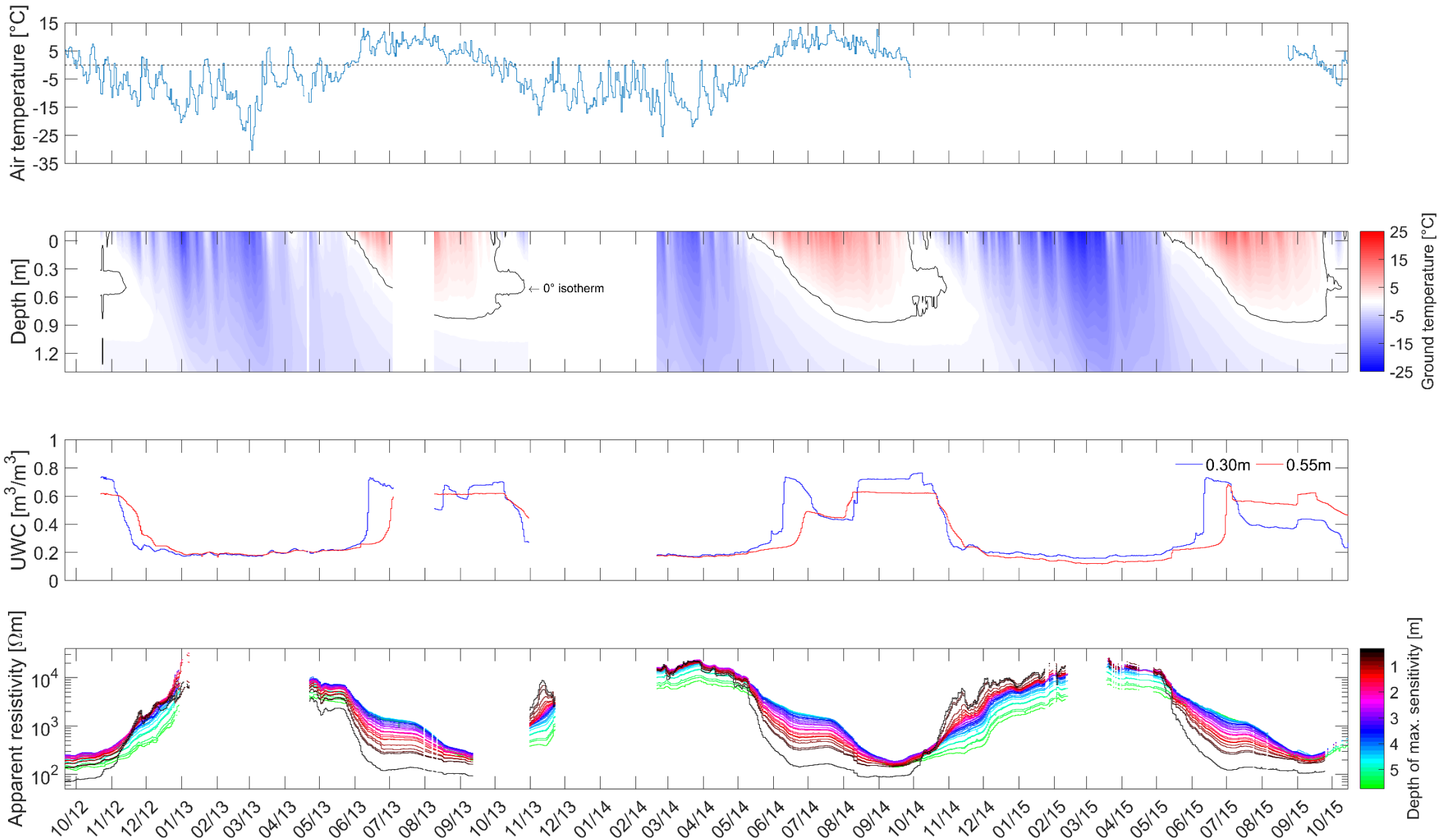
Soil grain size distribution:
55% clay (grain size < 2μm)
25% fine silt (grain size between 2 - 6μm)

Monitoring station in Ilulissat, West Greenland (69° 14´ N, 51° 3´ W, 33 m a.s.l.)

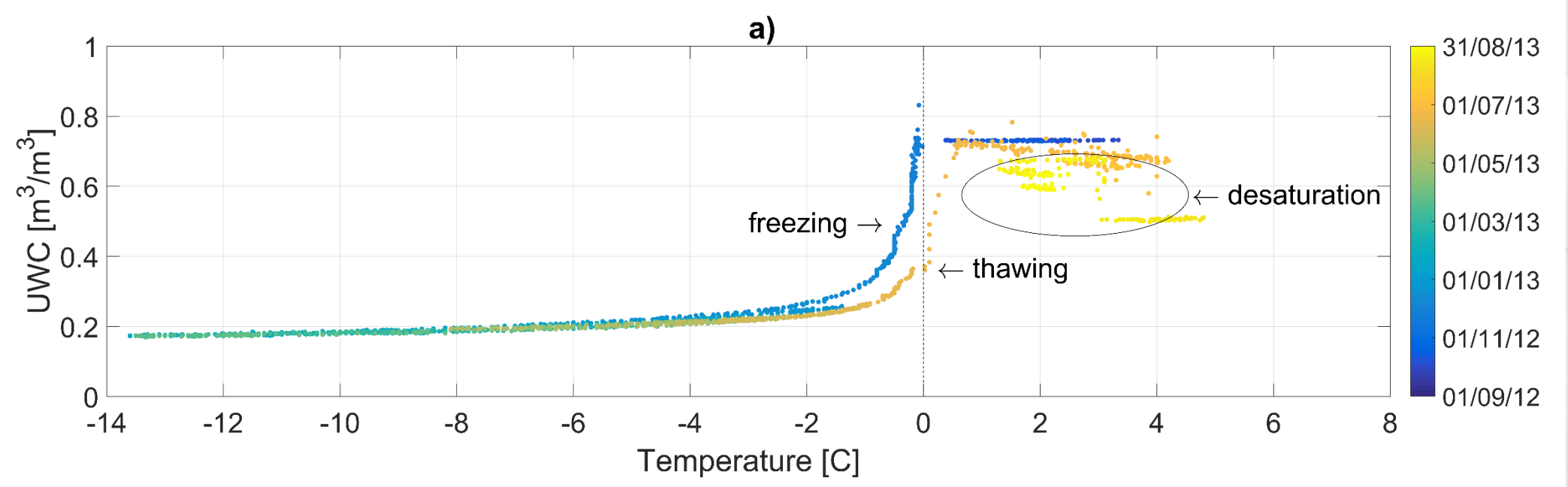




The raw monitoring data



Unfrozen water content *vs.* Ground temperature



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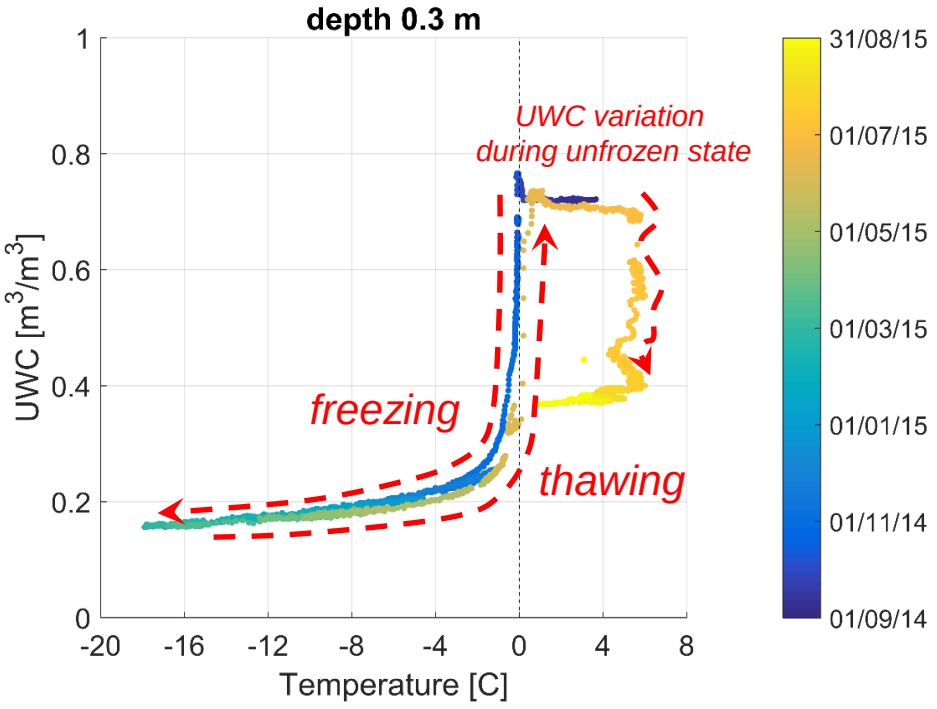
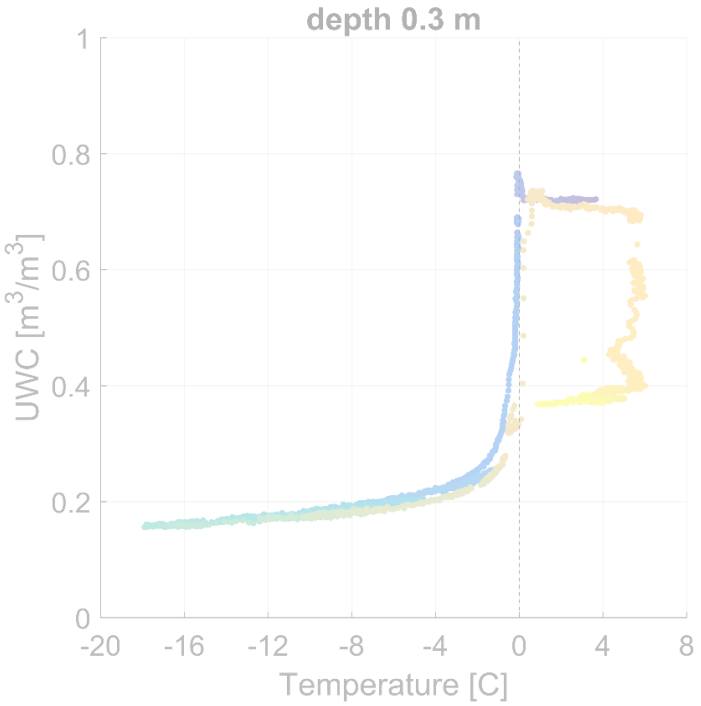
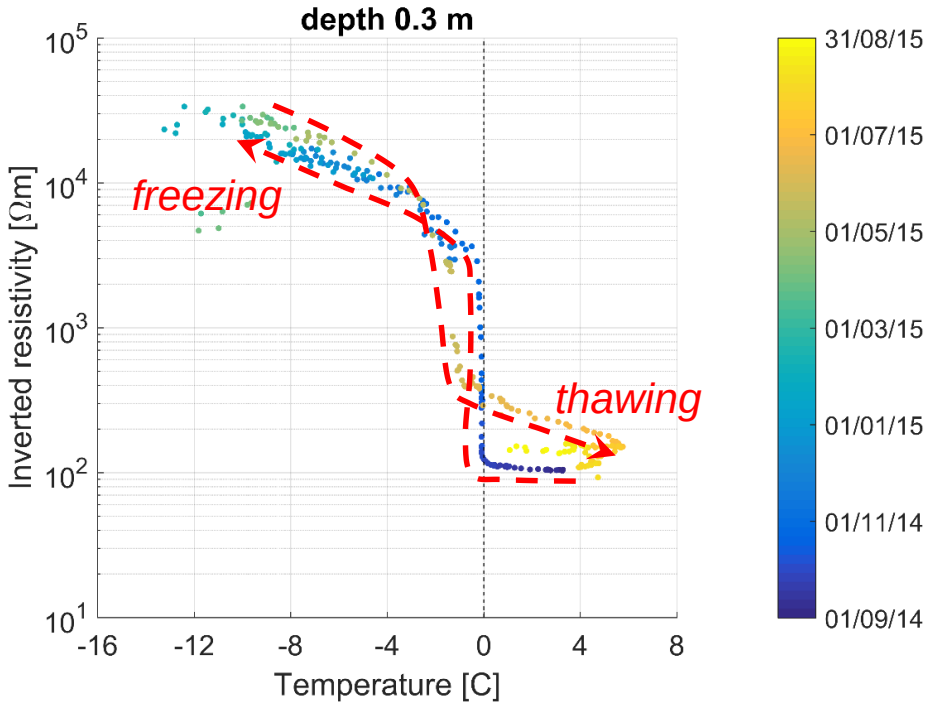
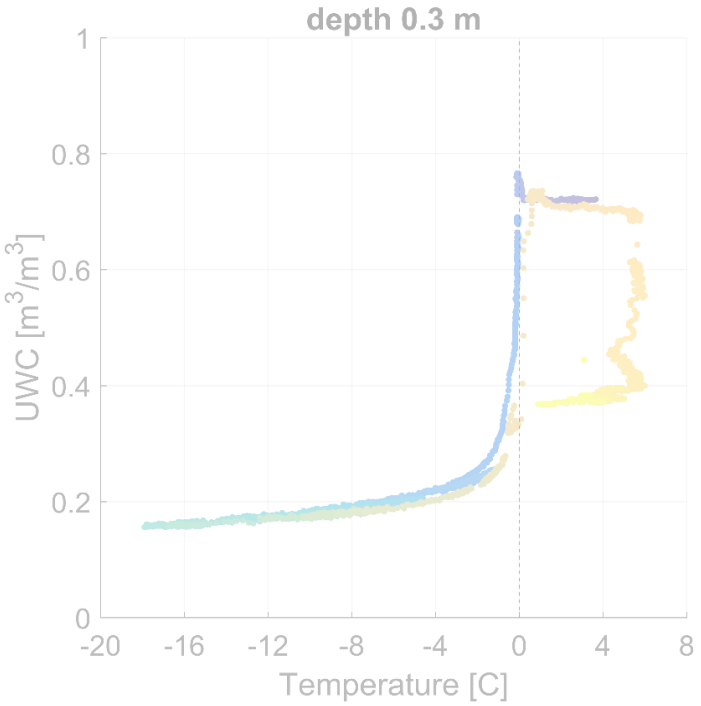


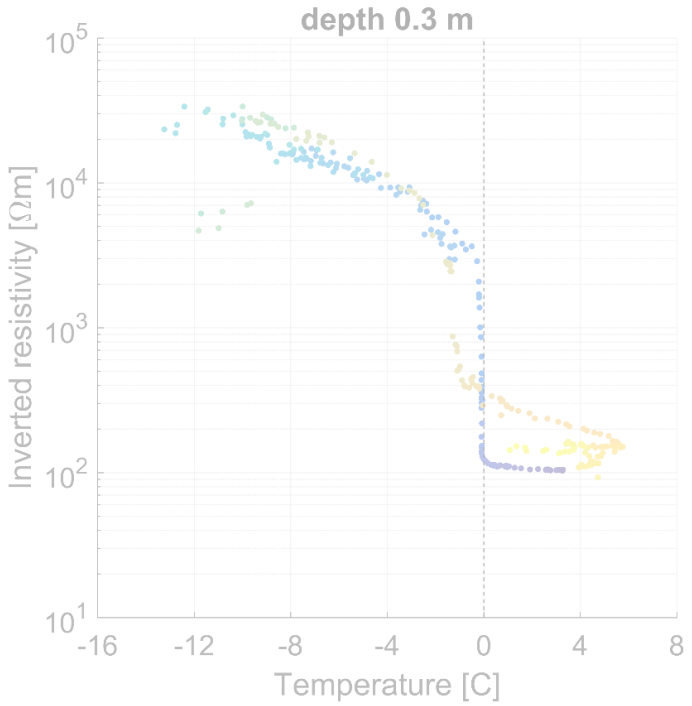
Inverted resistivity *vs.* Ground temperature

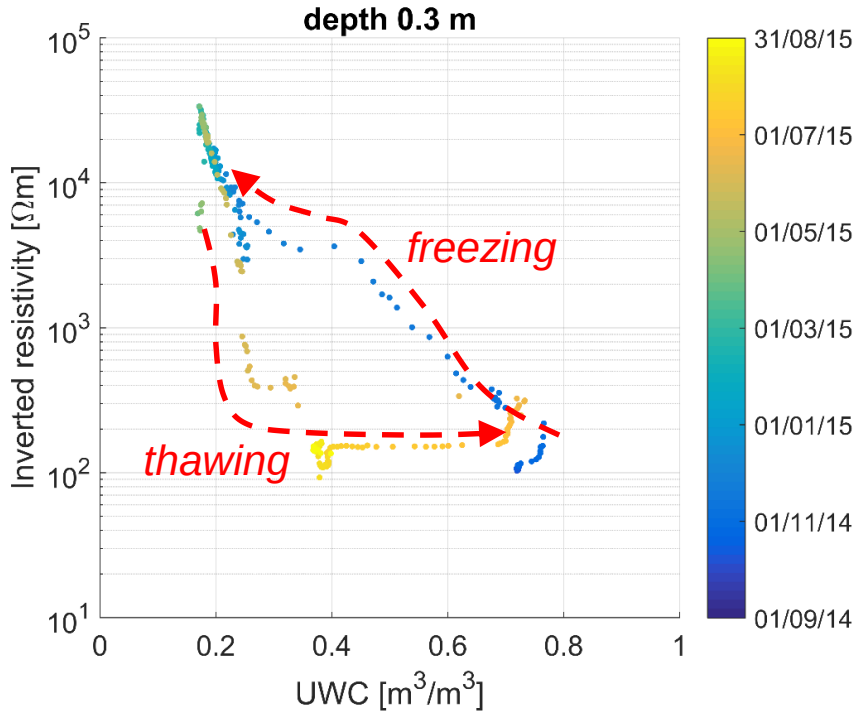




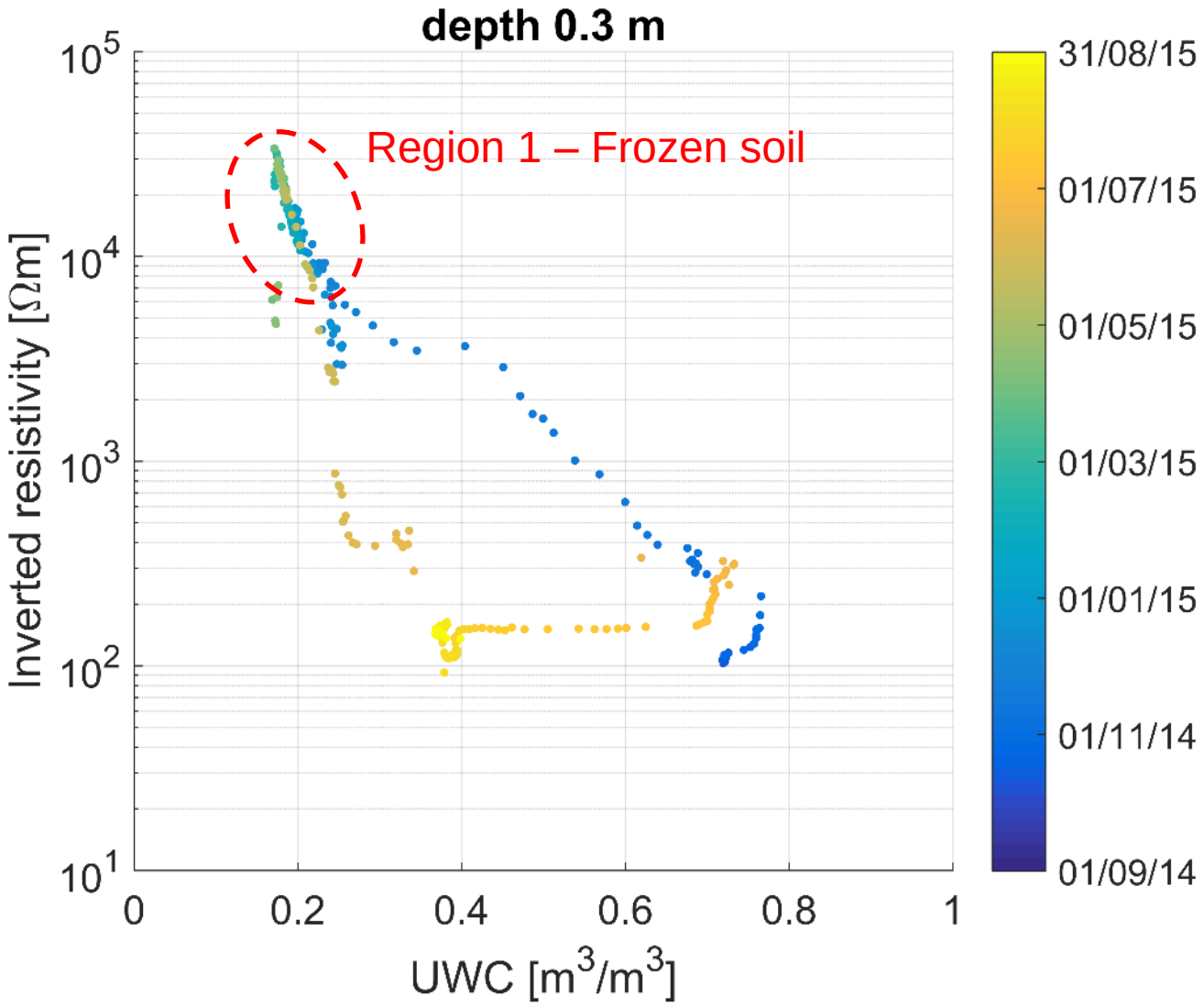
Inverted resistivity *vs.* Unfrozen water content





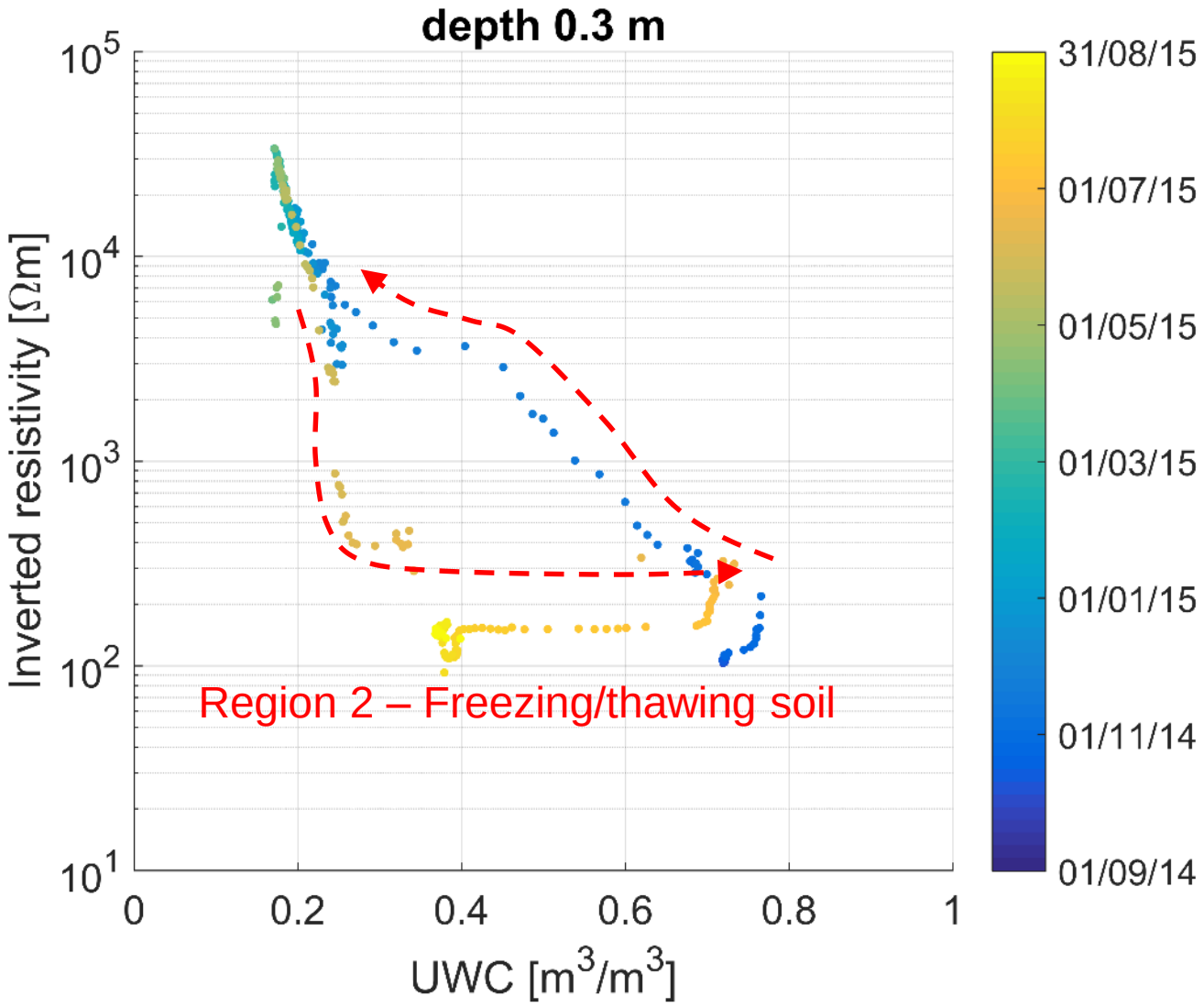


Inverted resistivity *vs.* Unfrozen water content



- Volumetric unfrozen water content 17 - 23%.
- Ground temperature up to -3°C.
- Resistivity changes rapidly even with small changes in liquid water content.
- No hysteresis is observed.

Inverted resistivity *vs.* Unfrozen water content



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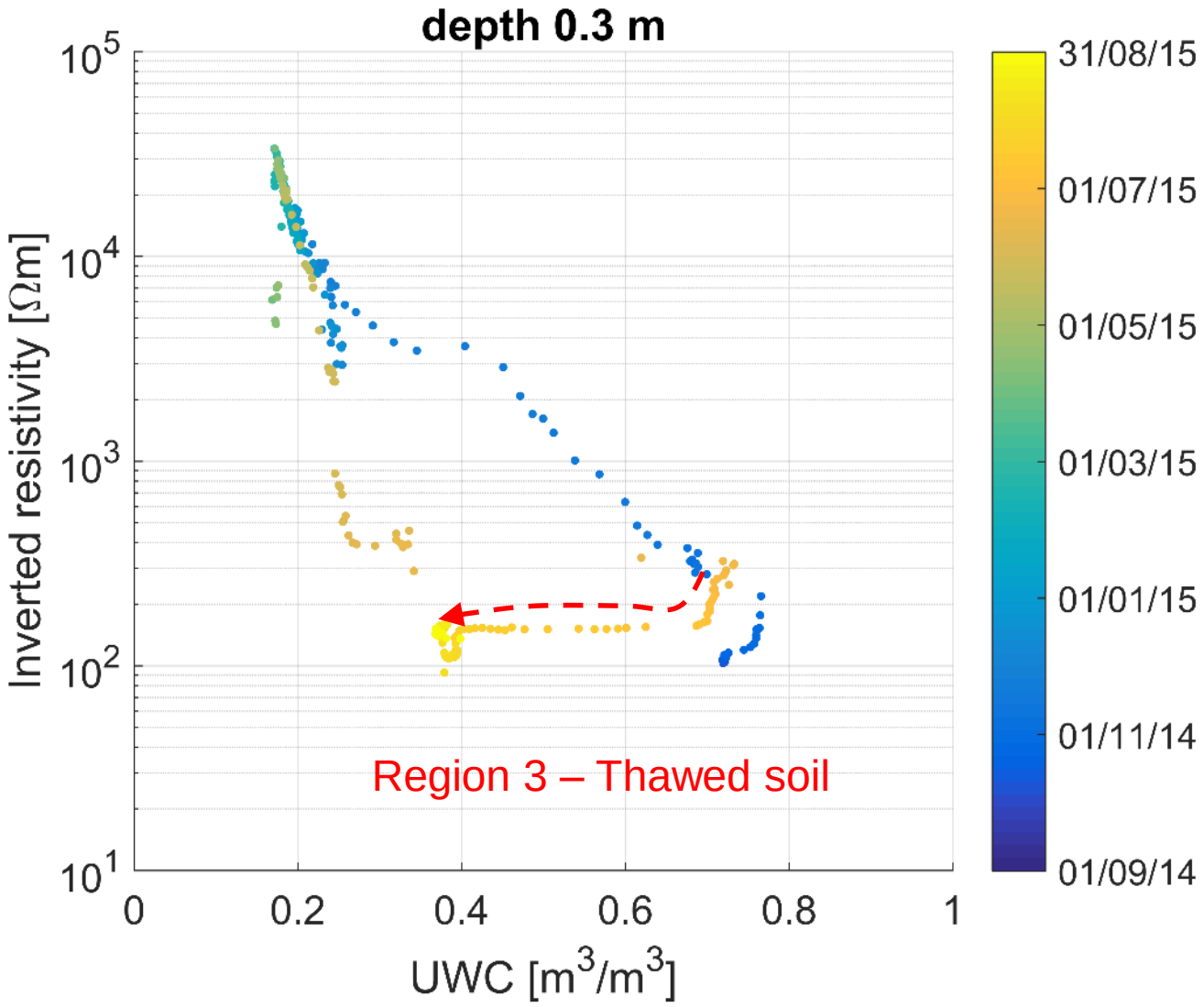
- Volumetric unfrozen water content 23 - 70%.
- Pronounced hysteresis in the freeze-thaw cycle
- Resistivity during freezing consistently higher (~ factor of 10) than during thawing at the same unfrozen water content

Inverted resistivity *vs.* Unfrozen water content



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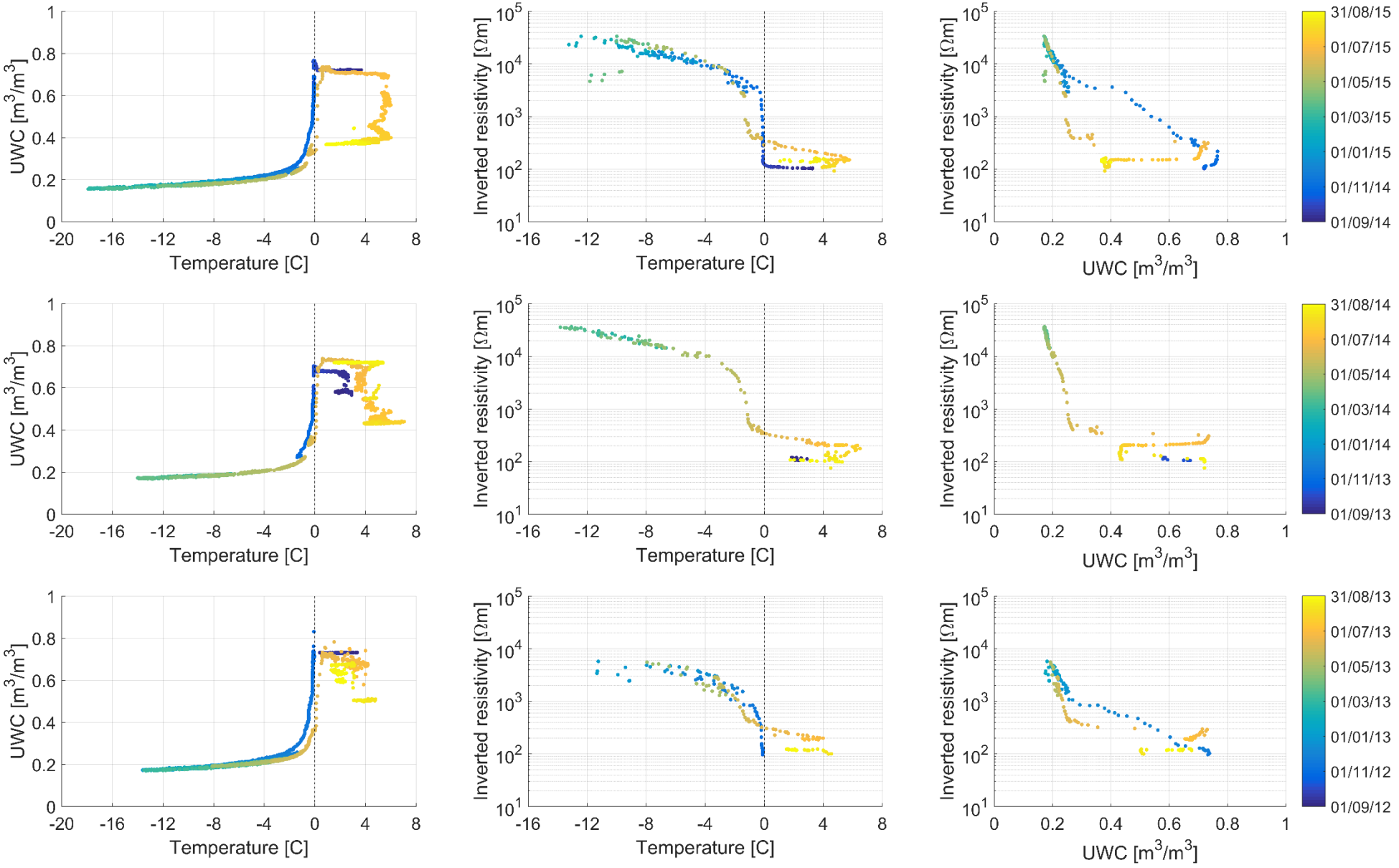
- Volumetric unfrozen water content 23 - 70%.
- Pronounced hysteresis in the freeze-thaw cycle
- Resistivity during freezing consistently higher (~ factor of 10) than during thawing at the same unfrozen water content

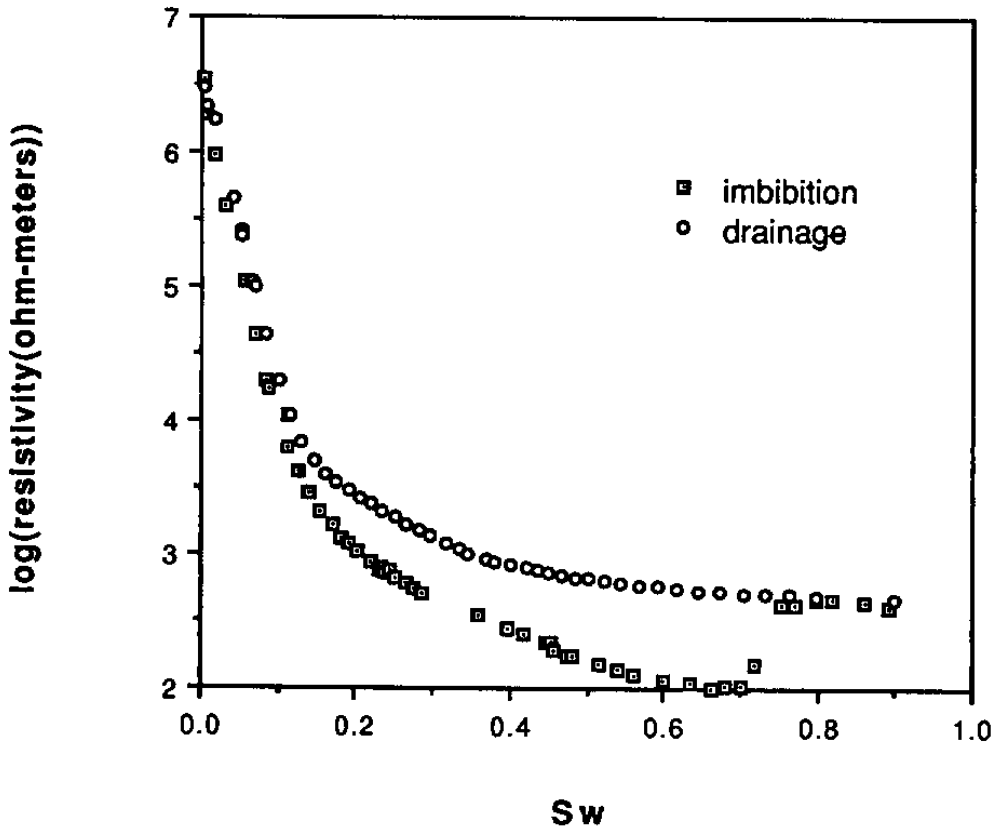
- Following the complete thaw in June/July and up until the beginning of the new freezing cycle, ground resistivity changes are not clearly related to changes in unfrozen water content

Consistent pattern every year …

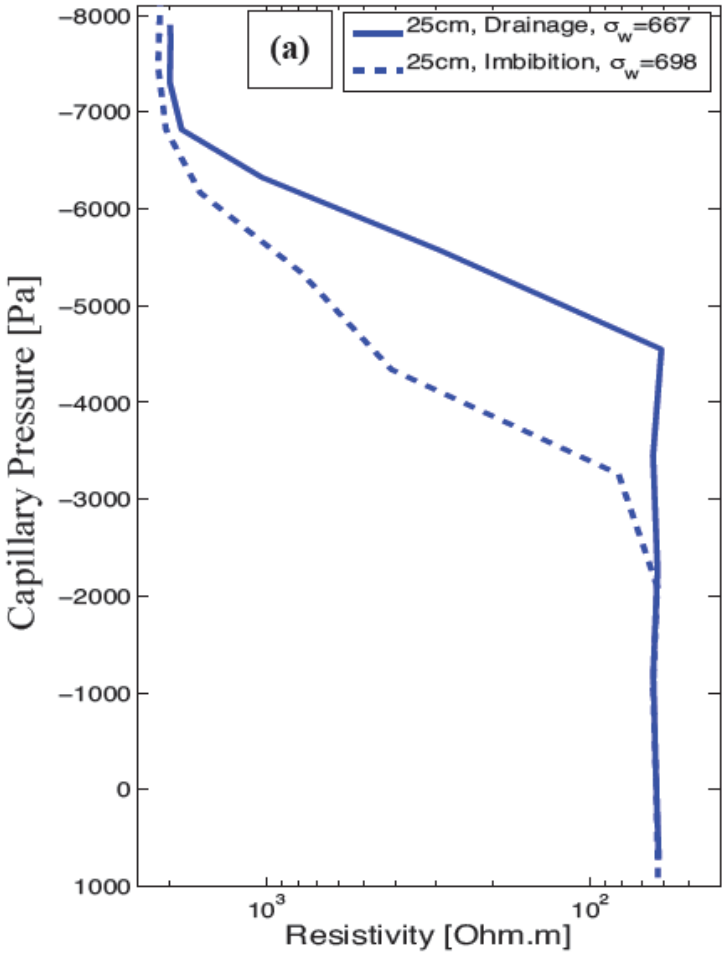


Timescale
2012 - 2015

Resistivity hysteresis in partially-saturated sandstone (Knight, 1991)



Resistivity hysteresis during imbibition and drainage cycle (Ruggeri, 2015)



Suggested explanations (in laboratory studies):

- pore-scale fluid distribution associated with saturation history (Knight et al., 1987; Knight, 1991, Ruggeri 2015);
- surface conduction at the air/water interface resulting from charge density and zeta potential at the air/water interface (McShea and Callaghan, 1983; Laskowski et al., 1989; Knight, 1991).

Implications for modeling…

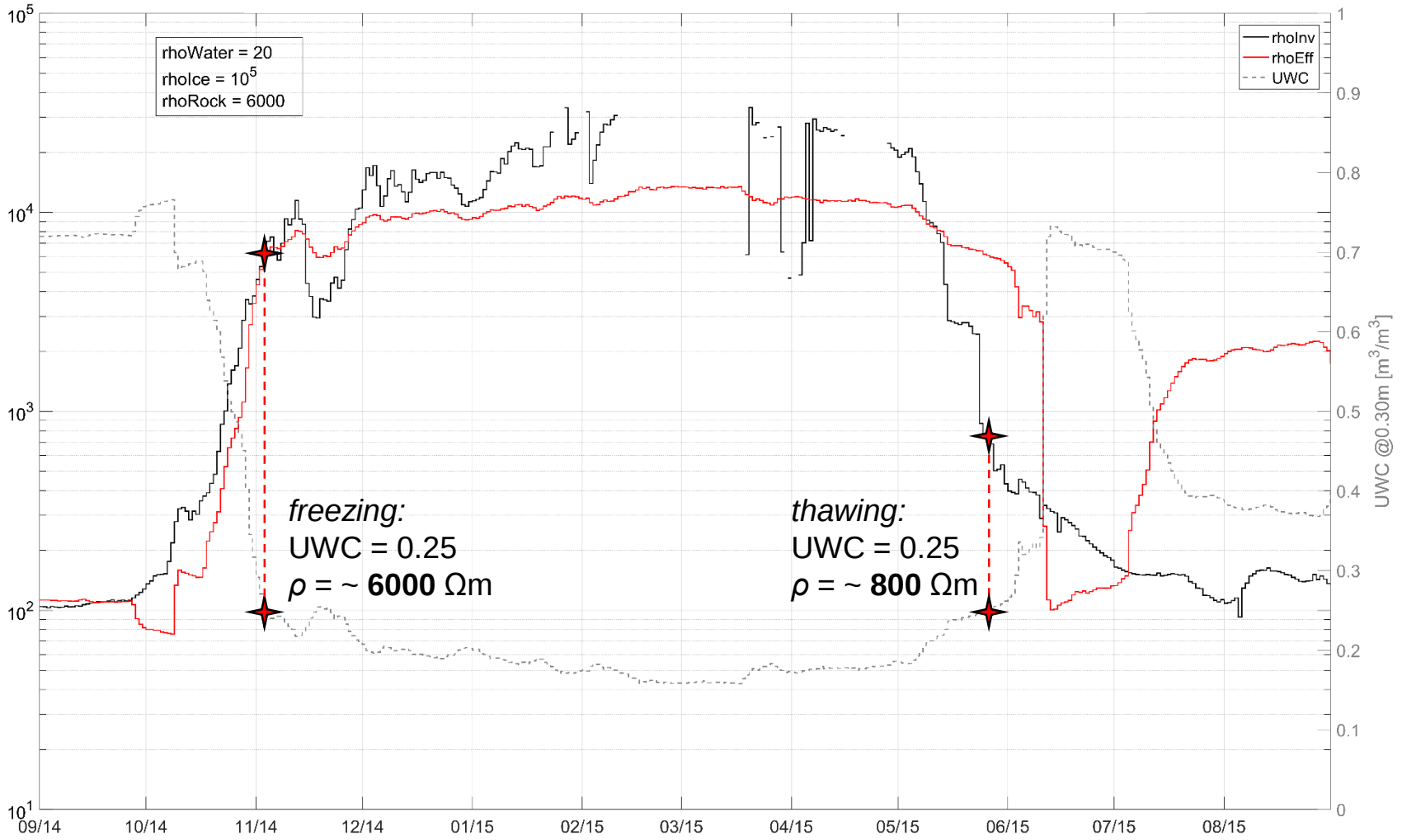
Field-measured UWC @0.3m

↓ *empirical power function (Lovell, 1957)*

Volumetric fractions of water, ice and soil particles

↓ *resistivity mixing relation (geometric mean, Archie,…)*

Effective resistivity @0.3m ↔ **Inverted** resistivity @0.3m



Conclusions

- Pronounced **hysteresis** of the unfrozen water content, ground temperature and resistivity
- The hysteresis can only be captured if **frequent sampling** is performed (i.e. at least 8 measurements per day for the unfrozen water content)
- The **resistivity hysteresis** complicates quantitative interpretation of time-lapse resistivity monitoring surveys in terms of changes in unfrozen water content in the seasonally-frozen portion of the ground

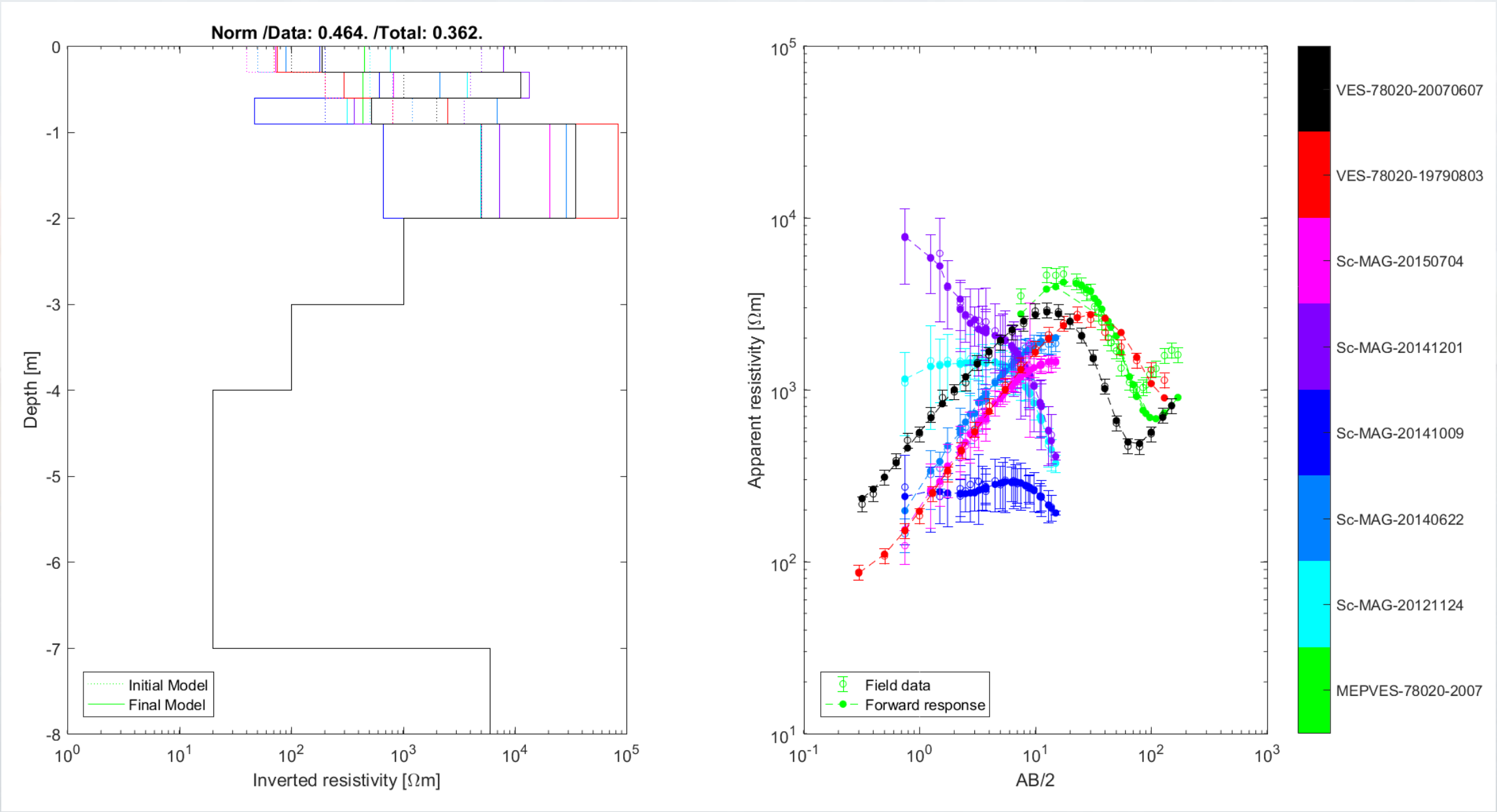
***References**:*

- Lovell, Jr. C. 1957. Temperature effects on phase composition and strength of partially-frozen soil. Highway Research Board Bulletin, 168.
- McShea, J.A. and Callaghan, I.C., 1983. Electrokinetic potentials at the gas-aqueous interface by spinning cylinder electrophoresis. *Colloid & Polymer Science*, *261*(9), pp.757-766.
- Knight, R.J. and Nur, A., 1987. Geometrical effects in the dielectric response of partially saturated sandstones. *The Log Analyst*, *28*(06).
- Laskowski, J.S., Yordan, J.L. and Yoon, R.H., 1989. Electrokinetic potential of microbubbles generated in aqueous solutions of weak electrolyte type surfactants. *Langmuir*, *5*(2), pp.373-376.
- Knight, R., 1991. Hysteresis in the electrical resistivity of partially saturated sandstones. *Geophysics*, *56*(12), pp.2139-2147.
- Ruggeri, P., Jougnot, D., Chavarriaga, R., Brandner, C., del Rocio Millán Ruiz, J. and Linde, N., 2015, April. Studying the hysteretic behaviour of unconsolidated sediments using an electroencephalography apparatus: a laboratory study. In *EGU General Assembly Conference Abstracts* (Vol. 17, p. 11381).

Thank you for your attention

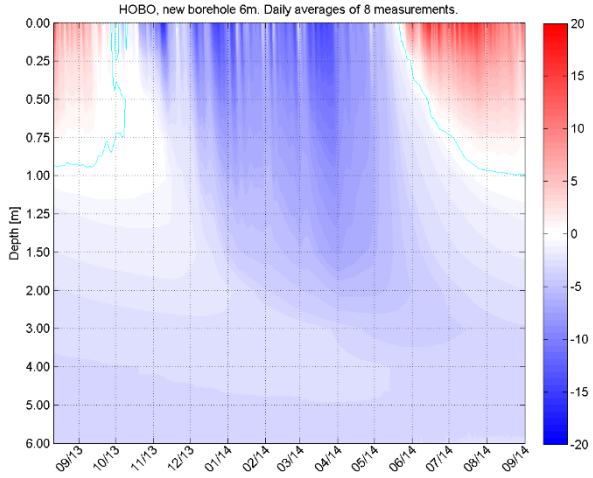
Questions…?

Constrained inversion using historical VES data

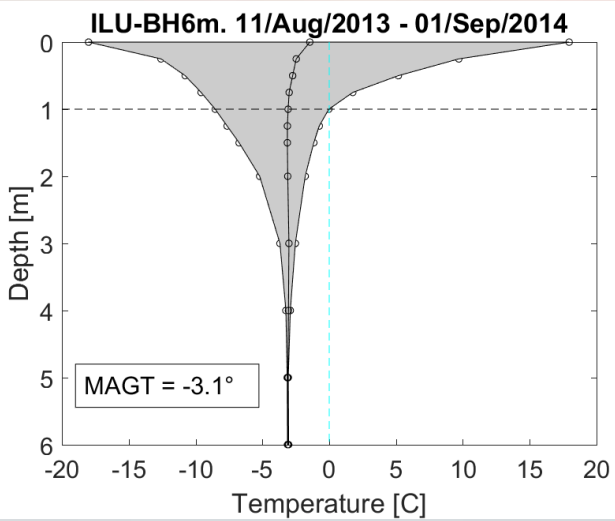


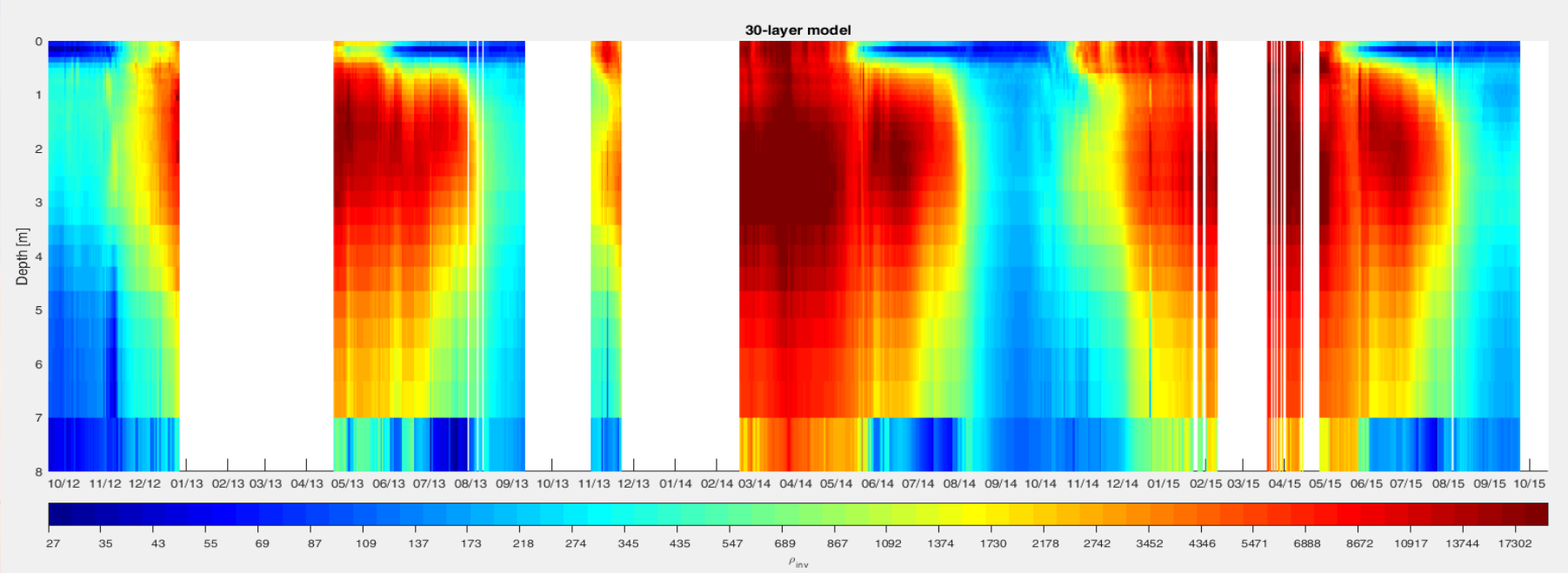
Unconstrained inversion – equivalency issues…

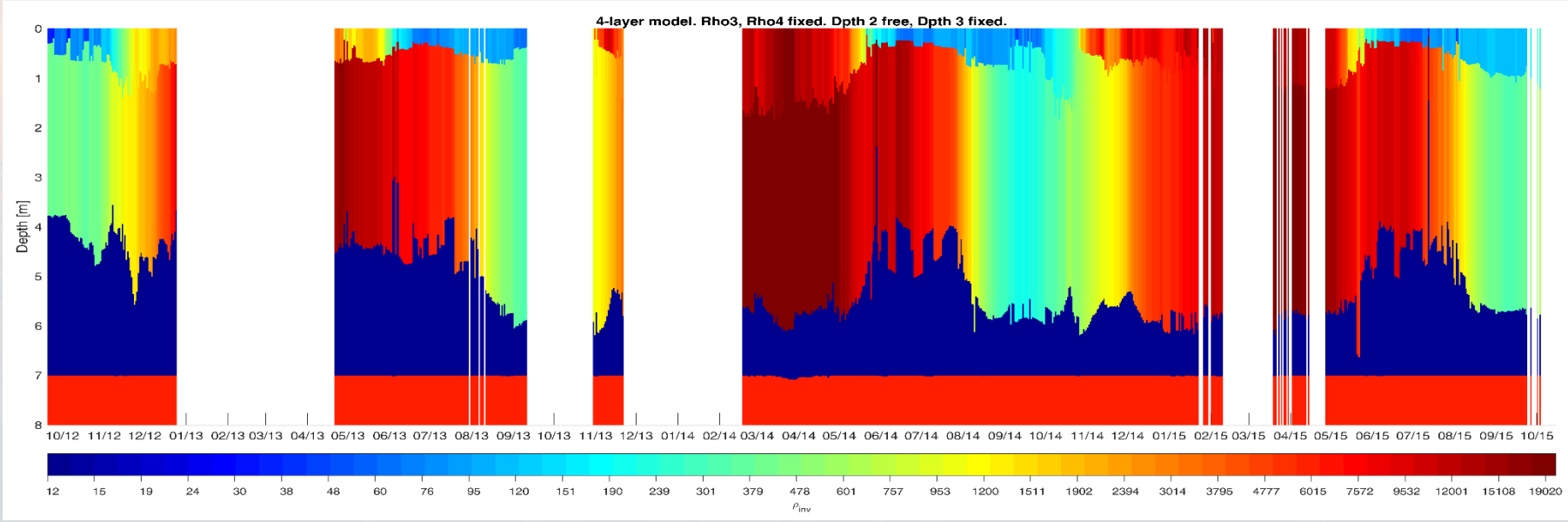
Ground temperature timeseries



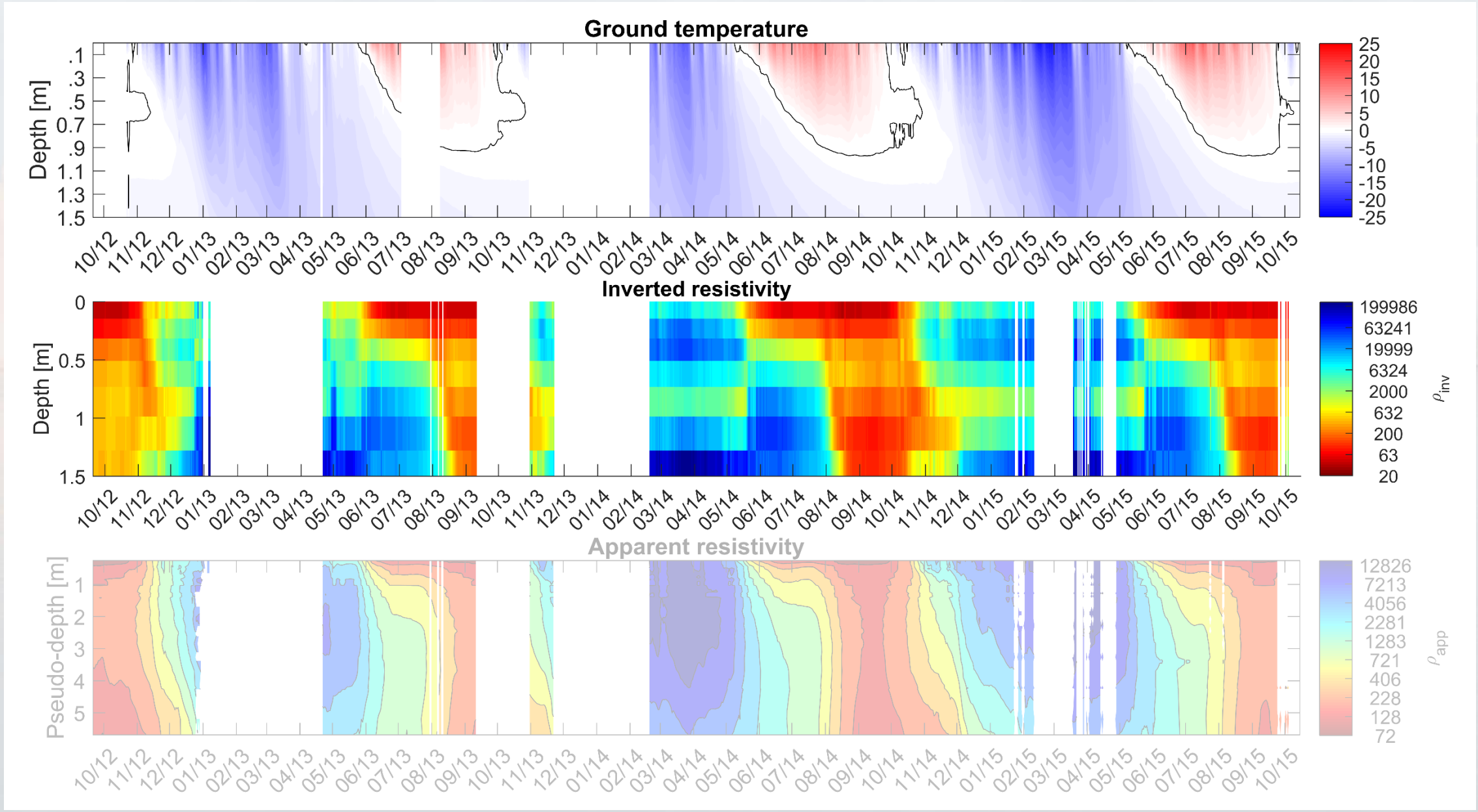
Temperature amplitude

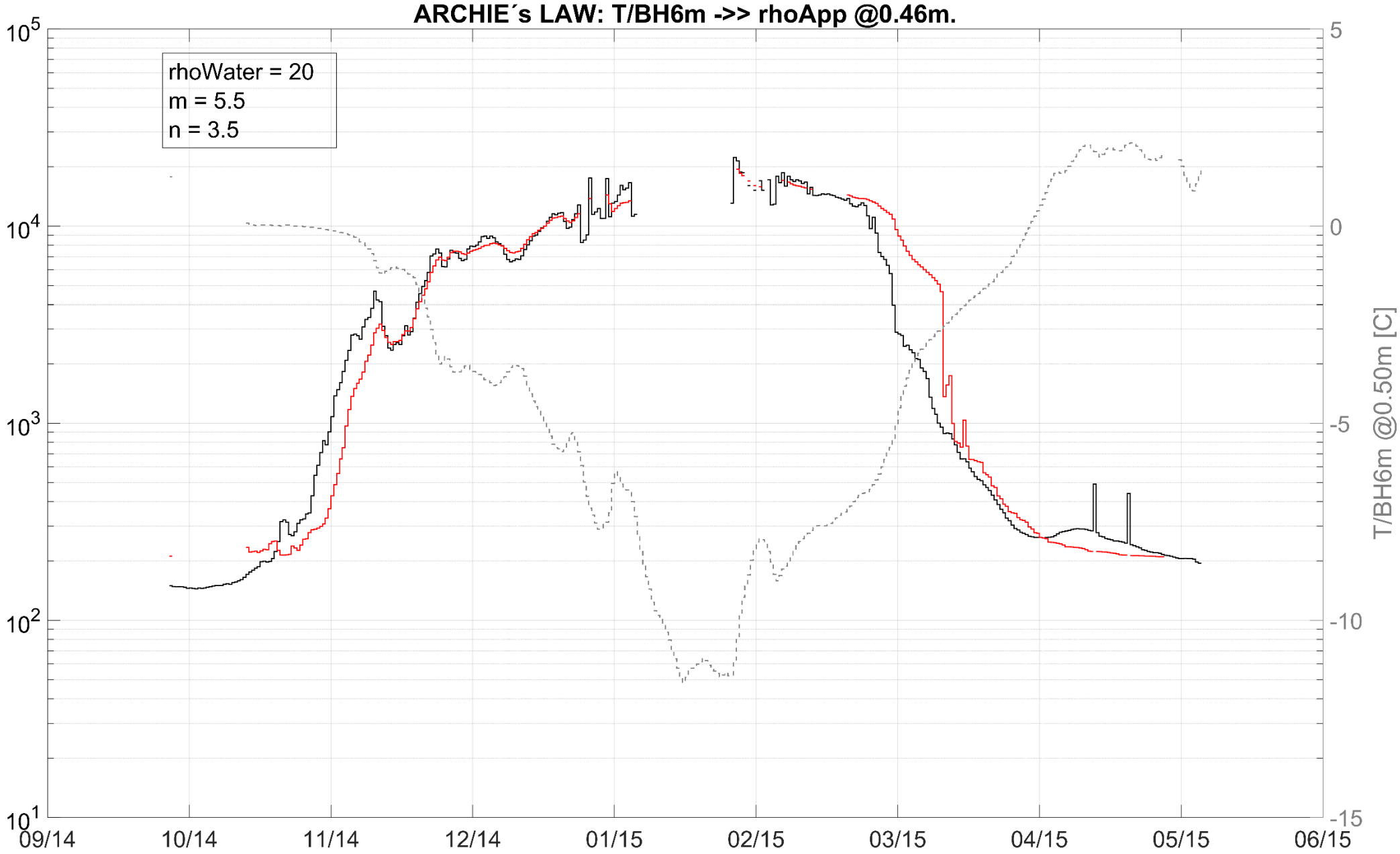


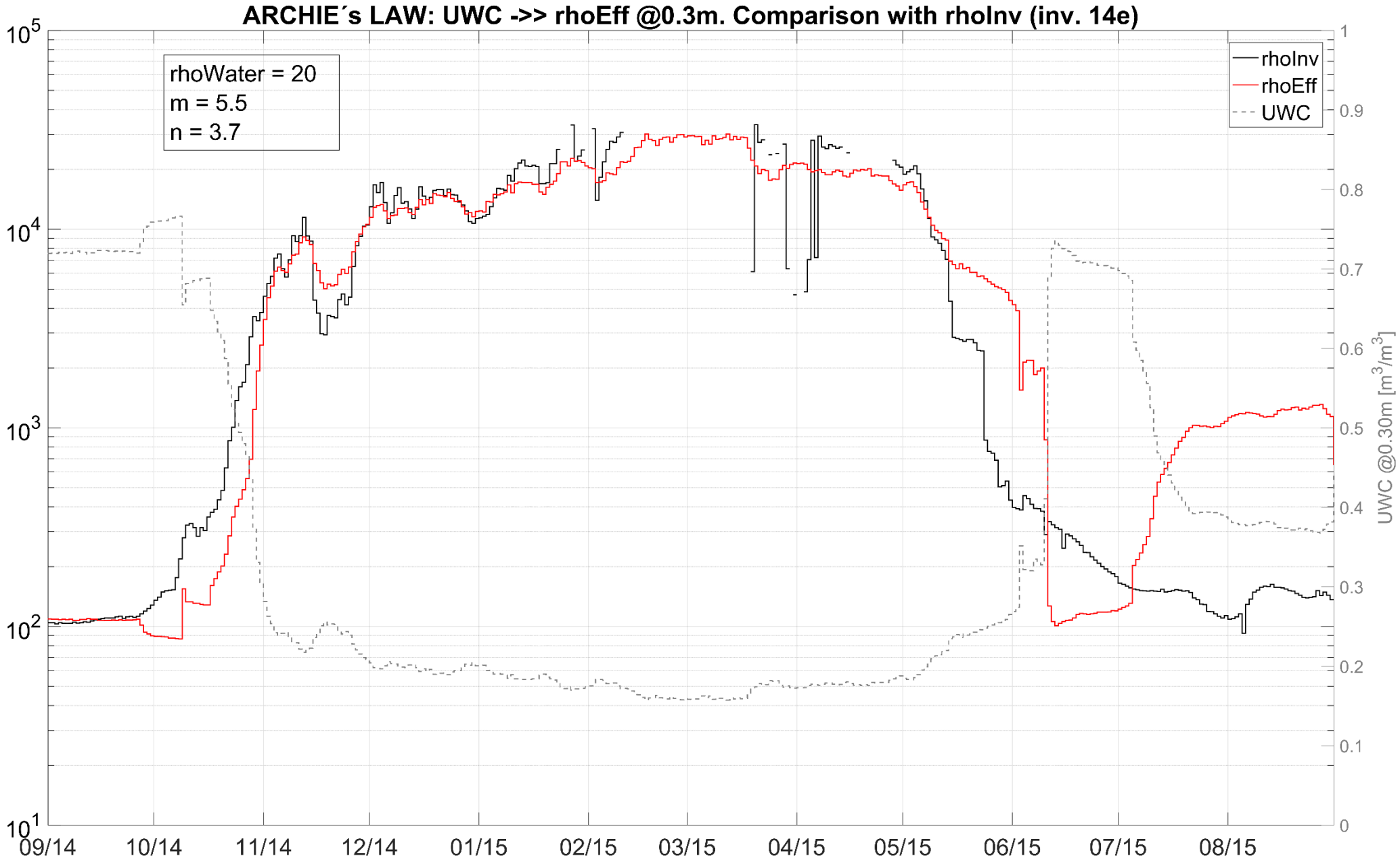




Processed 1D time-lapse resistivity data




ARCHIE´s LAW: T/BH6m ->> rhoApp @0.46m.
rhoWater = 20
m = 5.5
n = 3.5
10^5
10^4
10^3
10^2
10^1
09/14
10/14
11/14
12/14
01/15
02/15
03/15
04/15
05/15
06/15
5
0
-5
-10
-15
T/BH6m @0.50m [C]


ARCHIE´s LAW: UWC ->> rhoEff @0.3m. Comparison with rhoInv (inv. 14e)
rhoWater = 20
m = 5.5
n = 3.7
rhoInv
rhoEff
UWC
10^5
10^4
10^3
10^2
10^1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
UWC @0.30m [m^3/m^3]
09/14
10/14
11/14
12/14
01/15
02/15
03/15
04/15
05/15
06/15
07/15
08/15

3 years of monitoring data